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ENVIRONMENTAL RESTORATION  
DIVISION DMC**Y-12**THE RELATION OF GROUNDWATER TO MERCURY  
MIGRATION AT THE Y-12 PLANT AND  
THE HYDROLOGIC EFFECTS OF PROPOSED  
CLEAN-UP MEASURES**OAK RIDGE  
Y-12  
PLANT**

December 1985

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Environmental Technology Department  
Health, Safety, Environment,  
and Accountability Division**INTERNAL USE ONLY****CAUTION**

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for

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Oak Ridge, Tennessee 37831  
operated by  
MARTIN MARIETTA ENERGY SYSTEMS, INC.  
for the  
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CLEAN-UP MEASURES

This document was written by  
Geraghty & Miller, Inc., under  
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Energy Systems, Inc. The  
conclusions and recommendations  
expressed in this report are  
those of a Geraghty & Miller,  
Inc.

Oak Ridge Y-12 Plant  
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ENVIRONMENTAL RESTORATION  
DIVISION DMC

FINAL REPORT  
Y/SUB/85-00206C/5

# The Relation of Ground Water to Mercury Migration at the Y-12 Plant and the Hydrologic Effects of Proposed Clean-up Measures

Prepared for


MARTIN MARIETTA  
ENERGY SYSTEMS, INC.  
Oak Ridge, Tennessee

DECEMBER 1985

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AT THE Y-12 PLANT AND THE HYDROLOGIC EFFECTS OF  
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## 1.0 INTRODUCTION

### 1.1 OBJECTIVES

Geraghty & Miller, Inc., (G&M) was retained by Martin Marietta Energy Systems, Inc., (Energy Systems) in January 1985 to investigate mercury contamination in ground water at the Y-12 Plant in Oak Ridge, Tennessee. The plant is owned by the U.S. Department of Energy and is operated by Energy Systems. Objectives of the study were to (1) determine the role of ground water in the migration of mercury and (2) evaluate the hydrologic effects of proposed remedial actions for reducing mercury migration.

This report describes the results of the investigation; Chapter 2.0 is a summary of the findings. Chapter 3.0 describes the geology and ground-water flow patterns. Chapter 4.0 discusses how mercury migrates in ground water, and Chapter 5.0 evaluates the effects of the proposed renovation of the drainage system on ground-water flow and mercury migration. Potentiometric surface maps are presented in Appendix A.

### 1.2 BACKGROUND

Mercury used in industrial processes at the Y-12 Plant has been identified in the soils, ground water, and storm drains. Figure 1 shows where mercury has been used and where spills have occurred. The mercury is generally associated with the areas westward from Building 8110 and eastward from



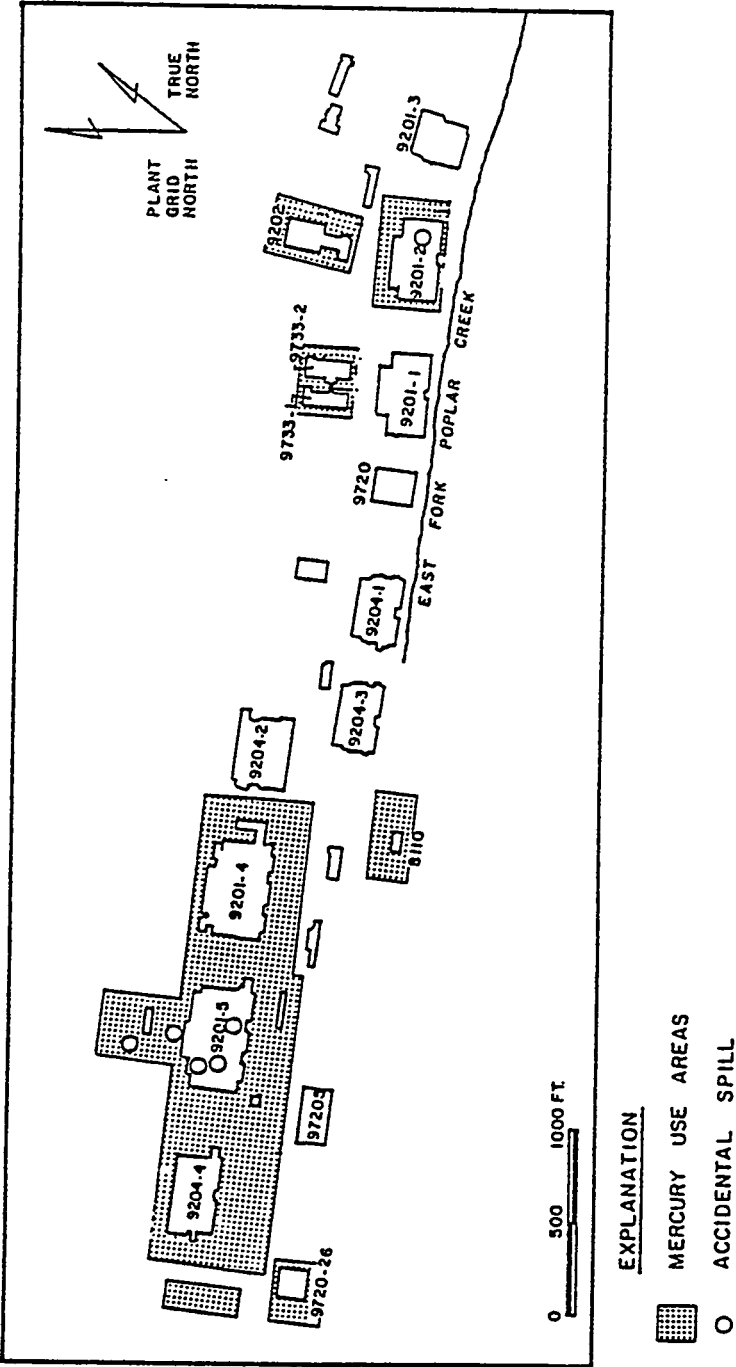


Figure 1. Location of Areas of Mercury Use and Accidental Spills, Y-12 Plant, Oak Ridge, Tennessee.

Building 9733-1, which are designated in this report as the "western area" and "eastern area," respectively.

Energy Systems has provided G&M with a large amount of data on laboratory analyses of mercury concentrations, the hydrologic system, and the storm drain system in areas of mercury contamination. These data include a description of a visual inspection of the storm drains and the results of drilling and sampling programs in the plant and its vicinity. The visual inspection revealed that significant deterioration of the drains had occurred, and the drilling and sampling programs indicated that mercury was present in ground water and, to a greater extent, in soil. Locations of the major drains are indicated on Figures 5, 8, and 9; the many small lateral drains are not shown on these maps.

Forty-three monitor wells were installed in the plant area as part of a mercury investigation conducted by Rothschild, et al (1984). At most of these monitoring sites, three wells were drilled to different depths, each being designated with a number followed by a suffix, A, B, or C (Figures 3 and 4). "A" indicates the well was finished in the surficial material, soil, or fill; "B" indicates the well was finished at an intermediate depth, usually in the zone of weathered rock overlying the bedrock; and "C" indicates the well was finished in the bedrock. Water levels in these wells have been measured weekly by Energy Systems personnel.

Ground-water and soil samples were collected at most monitor well sites and analyzed for mercury content.

Six other wells, in the vicinity of the S-3 Ponds, were installed by G&M in 1984. Ground-water and soil samples were collected at most of these monitor-well sites and analyzed for mercury content.

### 1.3 ACKNOWLEDGMENTS

The assistance and enthusiastic cooperation of George Kamp of Energy Systems have been of great value to G&M in this investigation. Previous reports on the geology and hydrology of the area, particularly the work of Rothschild, et al (1984), also have provided data on which the present interpretation of the mercury problem is based.

## 2.0 SUMMARY OF FINDINGS

1. Evaluation of the water-quality data indicates that mercury is rarely present in the ground water in dissolved form. The generally alkaline nature of the ground water and the presence of ions in the soils that readily combine with mercury reduce the possibility of mercury being taken into solution.

2. Elemental mercury is present in the soil at several sites in the plant and in discharges from some of the buildings. Migration in the ground-water system of elemental mercury in globules or in combination with soil particles is unlikely because of the extremely low velocities of ground-water flow. A considerable volume of mercury-contaminated water discharges to the storm drains from various contaminated buildings. These contaminated particles move by bedload transport and, to some extent, in solution when the discharge is acid, through the drain system to East Fork Poplar Creek. Contaminated soil particles may also be entrained in water that leaks into storm drains where the drains are below the water table.

3. Low pH caused by nitric acid effluent from the S-3 Ponds may lead to solution of mercury and transport in ground water moving toward East Fork Poplar Creek.

4. Storm drains divert some ground water from the unconsolidated material in areas where the drains are below

the water table. The ground water leaks into the drains and also flows through the surrounding gravel envelopes. Energy Systems is evaluating the possibility of sealing leaky storm drains to limit mercury migration to East Fork Poplar Creek. Calculations indicate that, if the leaking pipes are repaired, potential infiltration from the water table might be greater than some segments of the gravel beds could carry. Thus, the water table would rise, but the extent of the rise cannot be predicted from the available data. A rise in the water table would not cause significant problems in buildings with subdrains. Buildings 9201-4 and 9201-5, for example, are underlain by tile networks that drain to sumps equipped with pumps. Pump capacity is much greater than the capacity of the unconsolidated aquifer to yield water to the drain systems.

5. Energy Systems has considered the possibility of lowering the water table, in places where ground water may come in contact with mercury contamination, to prevent mercury migration to East Fork Poplar Creek. Because mercury is generally found in elemental form and is not transported via the ground-water system, the benefits of this remedial procedure would be minimal.

### 3.0 THE HYDROGEOLOGIC SYSTEM

#### 3.1 GEOLOGIC FRAMEWORK

The Y-12 Plant occupies the upper reaches of East Fork Poplar Creek in Bear Creek Valley, which is narrow and eroded into steeply dipping sedimentary rocks, principally shale. More resistant sandstones and dolomites comprise Pine Ridge and Chestnut Ridge, which stand about 200 ft above the valley floor immediately to the north and south, respectively (plant grid). Figures 2 and 3 are geologic maps of the western and eastern areas of the plant, respectively.

Bedrock is mainly shale with lenses and layers of carbonate rocks, limestone, and dolomite. Chestnut Ridge is underlain by relatively massive and resistant dolomites of the Upper Cambrian-Lower Ordovician Knox Group, which are siliceous in some places. There is evidence that the Knox Group contains joints and solution channels throughout Bear Creek Valley. Pine Ridge consists of older shale interbedded with sandstone and siltstone of the Rome Foundation.

The Maynardville limestone consists mainly of micro-crystalline, oolitic, dolomitic carbonates. This formation is reported to be as thick as 360 ft and is in gradational contact with the overlying Knox (Law Engineering, 1983). Numerous solution cavities of various sizes have been noted in the Maynardville, especially in the upper parts of the limestone along bedding planes. The Nolichucky shale member

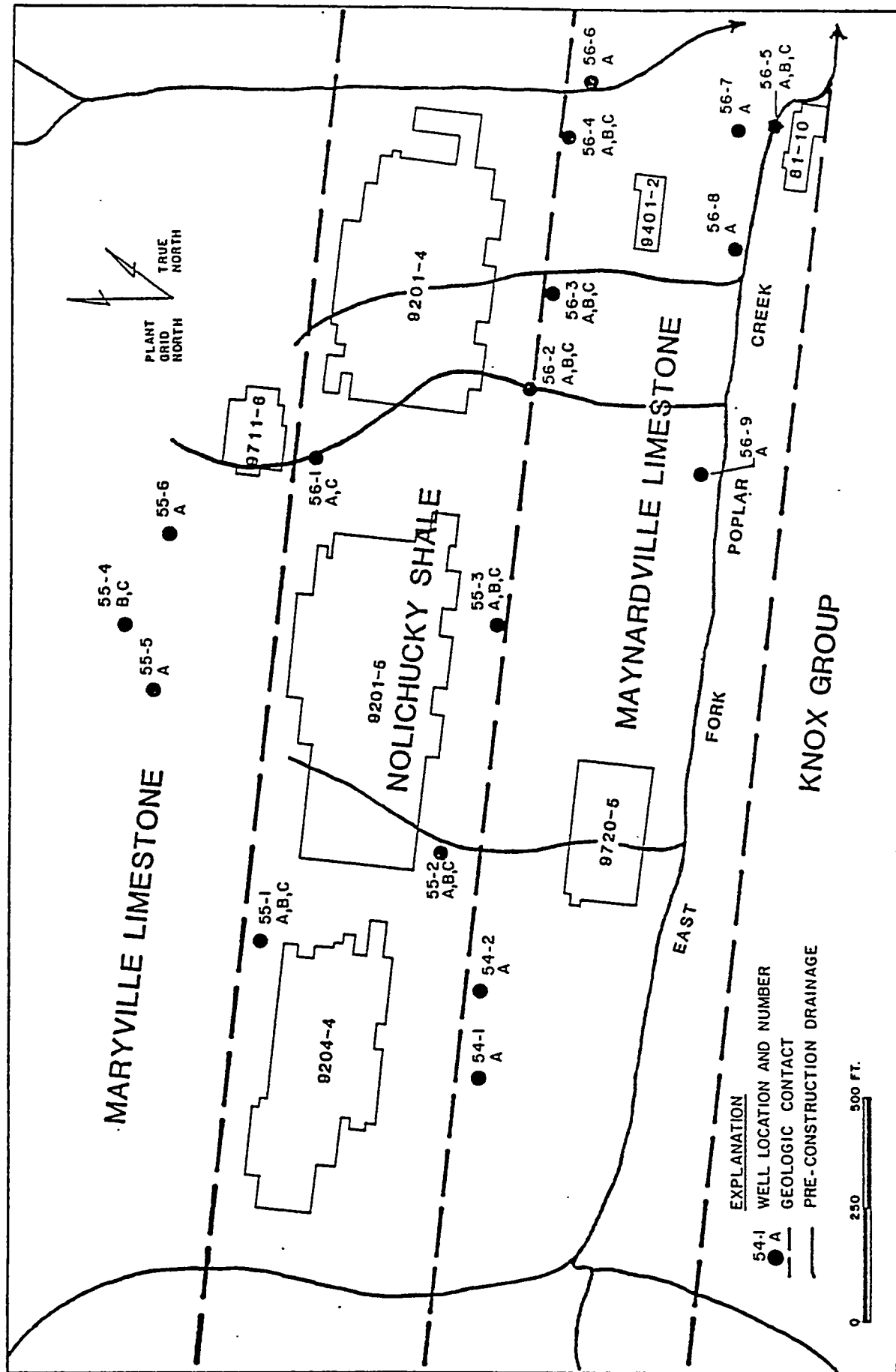


Figure 2. Geology, Pre-Construction Drainage, and Location of Test Wells in the Western Area of Interest.

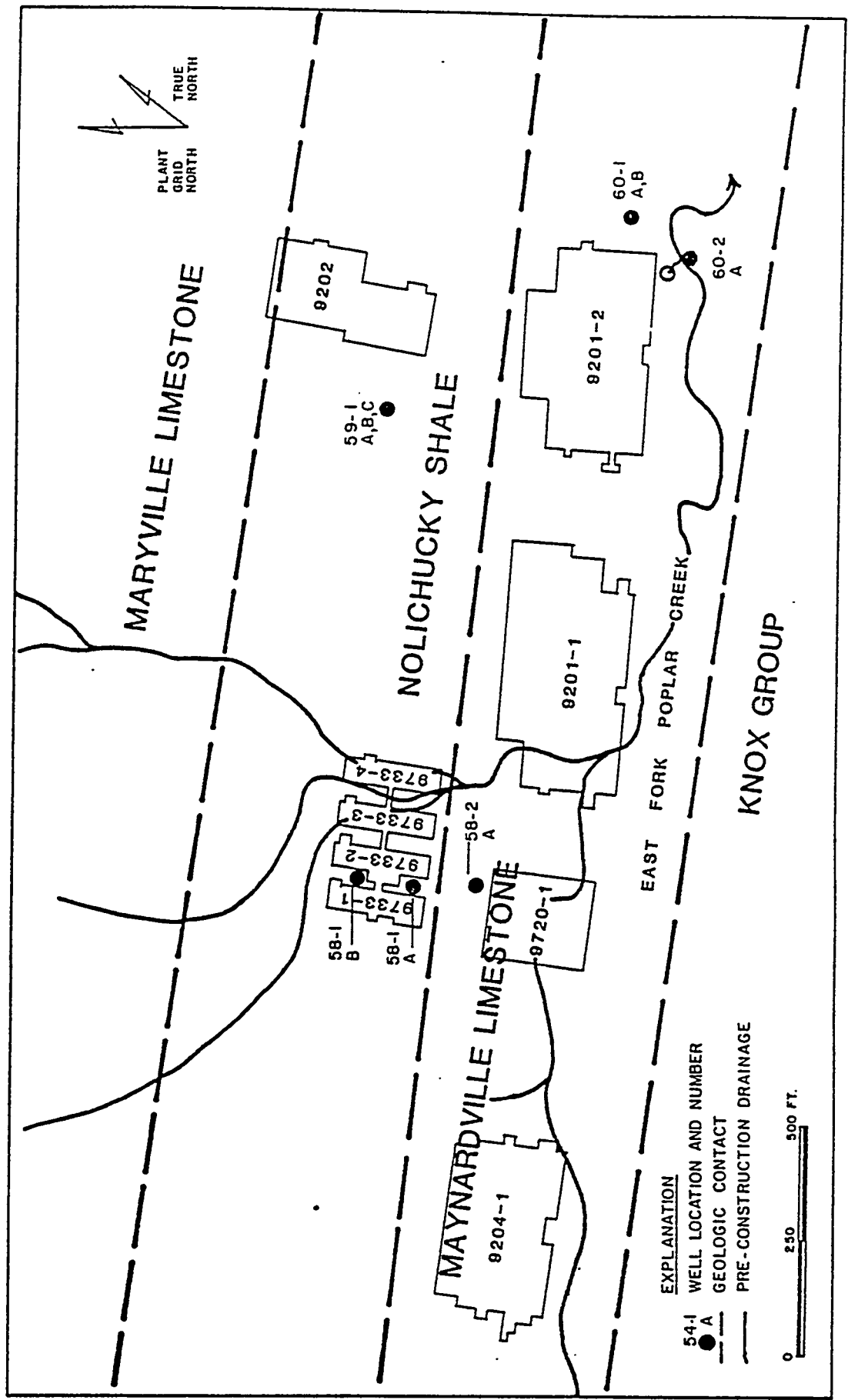


Figure 3. Geology, Pre-Construction Drainage, and Location of Test Wells in the Eastern Area of Interest.



dips under the Maynardville along the northern part of the valley; it is commonly interbedded with lenticular shales/mudstones and limestones. The Nolichucky is in gradational contact with the underlying Maryville limestone. The upper 30 ft of the Maryville contains pebble conglomerates and calcareous mudstones/siltstones.

The original pore spaces in the bedrock have been compressed by tectonic forces that folded, faulted, and tilted the beds into their present steeply-dipping positions. Shale is the least permeable of the rock types in the area, and is also soft and plastic enough to be molded by stress rather than to be fractured. Thus, channels for movement of water through the shale beds are small and relatively sparse. Near-surface weathering of the shale results in a degree of secondary permeability, particularly along bedding planes and fractures; this permeability diminishes with depth.

The limestones and dolomites, commonly interbedded with the shale, are relatively hard and brittle. Fractures exist along the bedding planes; major fractures are marked by stream channels and gullies in the hillsides. Ground-water flow has progressively enlarged the fractures by dissolution of the carbonates. Sections of the Maynardville limestone are relatively pure carbonate rock, and solution channels developed in these zones underlie the axis of East Fork Poplar Creek and comprise the principal drain for water moving through the bedrock. The irregular bedrock surface is

mantled by a regolith of weathered rock which, in turn, is overlain by unconsolidated clayey rock material and fill. Thickness of the overburden ranges from near zero in some places to as much as 30 ft. Water from precipitation in the upper valley of East Fork Poplar Creek runs off rapidly owing to the low permeability of the clay soils.

### 3.2 GROUND-WATER FLOW

The major components of flow in the ground-water system are (1) movement through the unconsolidated weathered rock and fill under water-table conditions, and (2) flow along bedding planes, fractures, and solution channels in the consolidated rock, generally under artesian conditions. Extensive cut and fill operations, prior to construction of the plant, altered the original topography of the valley and led to replacement of the natural drainage ways by an extensive network of storm sewers. The natural hydrologic system also has been modified by discharges of water from the plant into the drains.

Water that recharges the unconsolidated material moves downward to the water table, then laterally downgradient to the axis of the valley where it discharges by seepage to form the baseflow of East Fork Poplar Creek. Some water from the shallow aquifer also moves downward to recharge the underlying bedrock. Natural recharge patterns have been modified by roofs and pavements, which now channel runoff to the storm drains. Recharge is limited to the slopes of the ridges

north and south of the plant, unpaved areas within the plant, and places where leaky sections of the storm drains lie above the water table.

Theoretically, ground water that recharges the ridges may have sufficient head to percolate downward to a regional flow system and drain to an area of discharge beyond the plant area. However, ground water in the valley is generally contained between the north and south ridges, and either drains to East Fork Poplar Creek or flows through solution conduits in the limestone along the axis of the valley in the same direction as surface runoff. Figure 4 illustrates the general structure of the bedrock and the manner in which ground-water flow is channelled along bedding planes and fractures.

Most of the data indicate that there is a potential for downward movement of water from the unconsolidated material to the bedrock. Wells finished in the Nolichucky shale, however, generally show an upward component of flow from the bedrock to the unconsolidated material. Apparently, the more permeable Maryville limestone transmits water in greater volume than the fracture system within the shale, resulting in a higher head within the deeper part of the shale aquifer. Where the fracture system leads upward, water may move up to enter the shallow aquifer. However, most of the water that enters the shale from the Maryville limestone to the north is

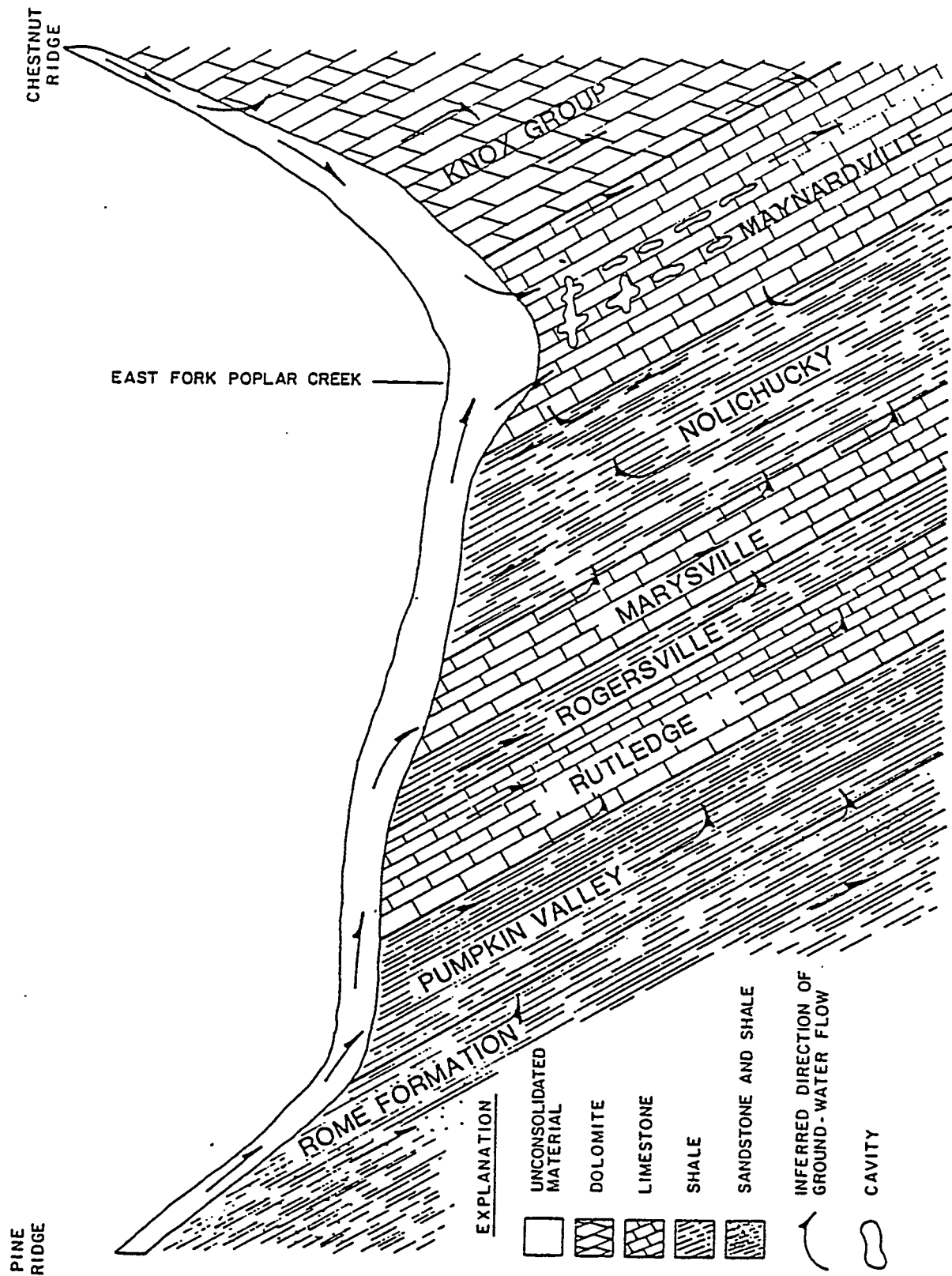


Figure 4. Generalized Geologic Section Through Bear Creek Valley.

probably discharged southward and downgradient to the Maynardville limestone.

Contours on the potentiometric surfaces of both the unconsolidated material and bedrock in the contaminated areas are shown in the maps of Appendix A for May 4 and September 17, 1984. The May measurements were the highest of the year in most wells; those in September were generally lowest. The maps illustrate the potential for ground-water movement downgradient, normal to the contours. The actual directions of flow are probably different locally, owing to the anisotropy of the geologic units. Ground-water movement in both the unconsolidated material and the bedrock is from areas of higher head, beneath the ridges north and south of the valley, toward the axis of the valley. Actual flow paths within the bedrock aquifer are not as smooth as the contours suggest.

Figure A-1 illustrates how the axis of the ground-water flow net has shifted northward from its natural alignment along the former creek bed. This shift is due, in part, to leakage from the unconsolidated material into the drains and their surrounding gravel envelopes, and, to an even greater extent, to the interception of recharge by the extensive areas of pavement and roofs, which divert recharge water directly to the storm-drain system. The contours on the water table, which are based on water levels in only 16

shallow wells, are highly generalized and do not reflect the localized influences of the drains on the natural hydrologic regimen.

#### 4.0 MERCURY MIGRATION IN GROUND WATER

##### 4.1 CHEMISTRY OF THE GROUND-WATER SYSTEM

The presence of elemental mercury in the soil at several sites in the Y-12 plant has been amply documented. Rothschild, et al (1984), reported the results of mercury analyses for 430 soil or mud samples and 113 ground-water samples from 35 soil borings and 43 wells. Although mercury was found in elemental form both in globules and adhering to soil particles, occurrence of mercury dissolved in ground water was negligible. The report concludes, in part, "... it does not appear that mercury is mobile in an aqueous phase..."

The potential for movement of mercury within the ground-water system hinges on the solubility of the mercury in natural water and the velocities necessary to move mercury in particle form. The following comments on the chemical activity of mercury in the environment are abstracted from publication number 874, U.S. Environmental Protection Agency (1980), "Hazardous Waste Land Treatment:"

"[1] Divalent mercury is rapidly and strongly complexed by covalent bonding to sulfur-containing organic compounds and inorganic particles. These particles bind as much as 62% of the mercury in surface soils.

[2] Mercury, as  $\text{Hg}^{3+}$ , is also bound to exchange sites of clays, hydrous oxides of iron and manganese, and fine sands.

[3] Mercury removal by adsorption to clay colloids appears to be pH dependent ... 20% to 30% of the observed Hg removal is due to adsorption by clay, and mercury removal from soil solution is favored by alkaline conditions. At high pH values, precipitates of  $\text{Hg}(\text{OH})_2$ ,  $\text{HgSO}_4$ ,  $\text{HgNO}_3$ , and  $\text{Hg}(\text{NH}_3)_4$  predominate and are very insoluble. Insoluble  $\text{HgS}$  and  $\text{HgCl}_3$  occur at all pH ranges."

A full discussion of the possible reactions of mercury in the natural environment is beyond the scope of this report, but the excerpts quoted above help to explain why dissolved mercury has not been noted, to any great extent, in the ground water at Y-12. Rothschild, et al (1984, p. 48), for example, reported that no wells yielded "clear" ground-water samples with mercury concentrations above 2 ug/l, although three samples contained mercury concentrations approaching 1 ug/l and nine other wells yielded "clear" ground-water samples with mercury concentrations "suggestive of low-level contamination (0.1 to 1.0 ug/l)." Mercury concentrations in ground water at Y-12 are invariably associated with muddy water; the mercury is apparently adsorbed or otherwise bonded to the clay and silt particles. Furthermore, iron, manganese, and sulfur are common constituents of



the shale bedrock in the area and these elements persist, in oxidized form, in the saprolite and soils. Iron-oxide stains are reported in most descriptions of fractures in the bedrock. The availability of these ions for chemical bonding with the mercury may help to explain the relatively slight concentrations in clear ground water.

Finally, the presence of bicarbonate ions from the weathered limestone and dolomite serves to keep the ground-water system in an alkaline condition. Thirty-nine samples of water from shallow wells showed a pH range of from 6.20 to 8.33, with an average value of 7.16. Only two samples showed a pH less than 6.5. Of 21 samples from the deep aquifer, pH ranged from 6.3 to 8.42 and averaged 7.53, with only one value less than 6.5. Thus, the natural ground-water system is generally alkaline and favors removal of mercury from solution.

Process water moving through the drain pipes is sometimes extremely acidic and capable of taking mercury into solution. In areas where the drains are above the water table, the potential exists for this dissolved mercury to leak into the ground-water system. It seems likely, however, that the natural alkaline conditions will cause the mercury to precipitate or combine with available oxides in the soil before it can move very far.

#### 4.2 INFLUENCE OF NITRATE EFFLUENT ON MERCURY MIGRATION

Concern has been expressed that nitric acid from the S-3 Ponds might move eastward through the ground and, by virtue of its acidity, take mercury into solution, carrying it to East Fork Poplar Creek and beyond. Figure 5 is a potentiometric map of the water table near the ponds, based on the few shallow wells in the headwater area between Bear Creek and East Fork Poplar Creek. Flow lines suggest a relatively slight component of shallow ground-water flow eastward from the S-3 Ponds. Flow in the deeper system, along bedding planes, is not yet well defined.

Figure 5 also shows the results of analyses for nitrate derived from the nitric acid at the shallow wells and several storm drain sites. (Data reported as  $\text{NO}_3$  from Rothschild [1984] are converted in Figure 5 to  $\text{N}/\text{NO}_3$ .) No discrete nitrate plume can be defined from these data.

The S-3 Pond area shown in Figure 5 occupies the interfluvium between Bear Creek and East Fork Poplar Creek, which hydrologically is a recharge area in which water would be expected to move downward from the shallow to deeper aquifers. However, the water level in well 53-1A, which is only 22 ft deep, is generally above land surface. Furthermore, the hydrograph of the well shows fluctuations that apparently are not related to rainfall. Water-level data for the S-3 Ponds are not available for this period so no correlation can be attempted. Well GW-109 (103 ft deep)

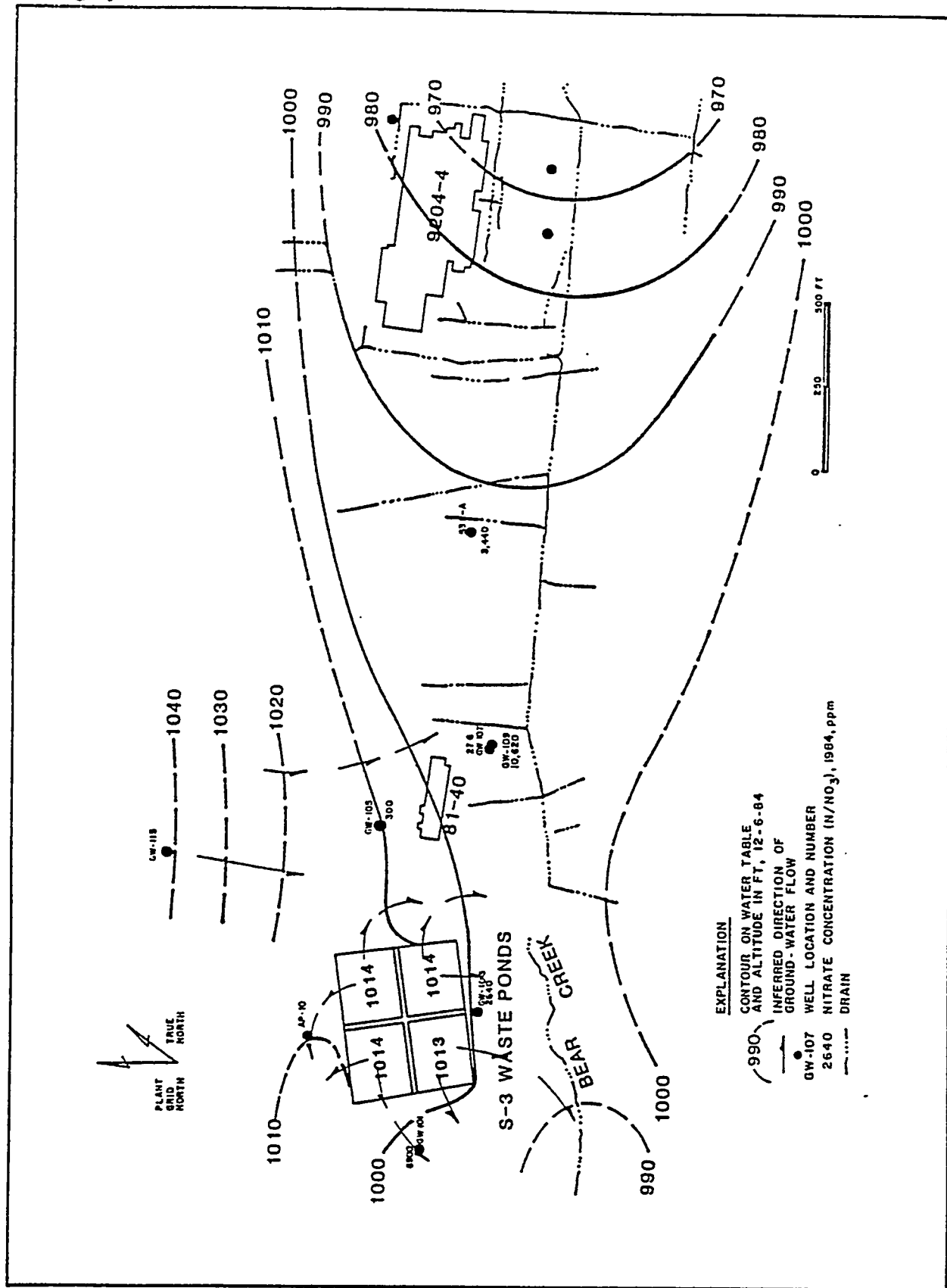


Figure 5. Potentiometric Surface, Unconsolidated Material, S-3 Ponds Area, December 6, 1984.

adjacent to GW-107 (14 ft deep) has water levels consistently higher than those in GW-107, indicating a potential for upward flow. Nitrate content of the deep well is 10,620 ppm (N/NO<sub>3</sub>) and pH is 4.9, as opposed to 27.6 ppm and 6.3 in GW-107. This seemingly anomalous hydrologic situation, coupled with the nitrate and pH data, suggests that effluent from the S-3 Ponds may be moving along fractures in the shale, eventually discharging upward at points in the shallow aquifer.

A preliminary report by G&M (1984) on contamination at the S-3 Ponds discusses the possibility of deep percolation of effluent from the ponds and subsequent lateral and upward movement along solution cavities parallel to Bear Creek. That study is continuing, and future interpretations of water analyses and head relations at different depths in the hydrogeologic system should provide more satisfactory information on whether, and to what extent, water from the S-3 Ponds affects mercury migration at the Y-12 Plant.

#### 4.3 GROUND-WATER VELOCITIES

Given that mercury in the soils and drains at Y-12 is in pure beads or globules, is adsorbed on clay particles, or is in chemical combination with other particulate matter, the question becomes "under what conditions might soil or ground water move with sufficient velocity to transport the particles of mercury?"

Unlike flow in the open channels or pipes, ground-water flow is laminar, rarely turbulent. Ground-water velocities are generally measured in ft per day, or even ft per year, as opposed to streamflow, which is measured in ft per second. Although ground water in the Y-12 area moves principally along bedding planes and fractures, these routes are generally filled with rock fragments so that the path of an individual water particle through the interstices is tortuous and slow.

Figure 6 illustrates the water velocity required to take particles of various diameters into suspension (upper curve) and the velocity below which they will settle (lower curve). Water velocity must be in excess of 100 centimeters per second (cm/sec) to take particles as small as .001 mm diameter (fine clay), into suspension. The smaller grain sizes, silt and clay require a more vigorous erosive environment than sand-size particles because of their adhesive qualities.

The steepest ground-water gradient in the Y-12 area is about 15 ft over a distance of 250 ft, north of building 9201-4. Multiplying this gradient of 0.06 by the average permeability of the shallow aquifer material ( $4.3 \times 10^{-4}$  cm/sec) (Rothschild, et al 1984) gives a velocity of  $2.6 \times 10^{-5}$  cm/sec), a value that is off the low end of the graph of Figure 6 by four orders of magnitude. A higher velocity of ground-water flow may be attained in the gravel beds in

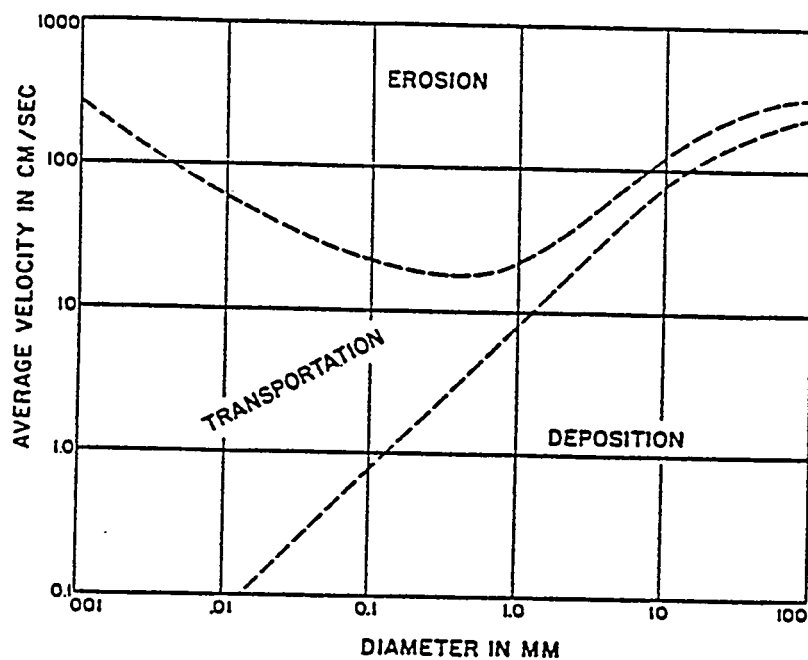


Figure 6. Graph Showing Relation Between Water Velocity and Particle Size of Sediment Taken Into Suspension (Adapted from Hjulstrom, 1939, in: Krumbein, W.C., and Sloss, L.L., 1963, Stratigraphy and Sedimentation, p. 203).

which the drain pipes are laid. Assuming a permeability of 0.5 cm/sec for the gravel and a gradient of .012 for the reach of the 60-inch drain from building 9720-5 to 81-10, the velocity is  $6 \times 10^{-3}$  cm/sec. Even in this "best case," the velocity of flow is clearly insufficient to move material in suspension.

There are two possibilities at Y-12 for turbulent flow of ground water that might entrain mercury-contaminated particles. The most likely is where a drain pipe, beneath the water table, has developed a leak and where ground water is moving downward into the unfilled pipe. In this case, soil particles and mercury would be entrained in the falling water. A cavity would develop in the soil or fill material above the leaky pipe, which could enlarge upward by spalling until it eventually reached land surface. Particles thus deposited in the pipe would be carried away by the relatively high-velocity flow in the pipe.

The second possibility is that ground-water flow through open solution conduits might reach critical velocities and carry particles in suspension. This is most likely in places where recharge to the conduit is through open holes or sinkholes, none of which have been reported in the Y-12 area. Presumably, most recharge to solution conduits occurs at depth, by seepage from the conduit walls. Point velocities in the unconsolidated material contributing water to the conduit are relatively low, in the range of laminar flow,

even though flow in the conduit itself may be quite rapid. Thus, the contribution of suspended particulate matter to the conduit would be negligible.

#### 4.4 EFFECTS OF REPORTED SPRINGS ON MERCURY MIGRATION

A spring that originally flowed about 500 gallons per minute (gpm) discharged from the limestone at the south wall of building 9201-2 (Figure 3). A pre-construction survey showed a funnel-shaped orifice in the limestone about 20 ft across and 20 ft deep. The spring was reported to have been plugged with cement prior to construction of building 9201-2. Although the discharge may have been diverted, it seems likely that the conduit leading to the spring orifice is responsible for maintaining a relatively high water table in the immediate vicinity.

Several drains enter East Fork Poplar Creek from the south side of building 9201-2. The purpose of all the drains is uncertain, but it seems probable that at least one of them was installed to divert water from the plugged spring conduit. Not all the drains have been sampled; discharge and mercury content of the three sampled drains were: 3.7 liters per second (l/s), 27.0 ug/l; 13.0 l/s, 2.2 ug/l; and 11.4 l/s, 2.3 ug/l.

A second spring was reported discharging mercury-contaminated water into a sump at the southwest corner of Building 9201-4. Subsequent investigation revealed that the



water was from a network of tiles, set in gravel, beneath the building. The network of subdrains, apparently designed to protect the buildings from high ground water, drain to eight sumps beneath both Building 9201-4 and 9201-5. Pumps discharge a total of about 500,000 gallons per month from the 16 sumps.

Figure 7 shows the rate of pumpage from each sump, in gallons per minute, for a 13-day period ending July 1, 1985, along with contours on the water table from May 17, 1985. Although six weeks separate the two sets of data, the water table probably did not fluctuate to any great extent (compare with Figures A-1 and A-2). The data show that the water table lies well below sump levels except in the northwest corner of Building 9201-5.

The different rates of pumpage from various sumps suggest local sources for the water. Pumpage from only three of the sumps, two in the southeast corner of Building 9201-5 and one in the southwest corner of 9201-4, constitutes 50 percent of the total discharge. Recharge from roof or pavement runoff may be reaching the water table locally and draining to the sumps. Such anomalies would not be apparent in the generalized contours of Figure 7. It seems more likely, however, that the water is coming from within the buildings.

The sump-pump capacity for each building is about 3.5 million gallons per day -- more than 100 times greater than

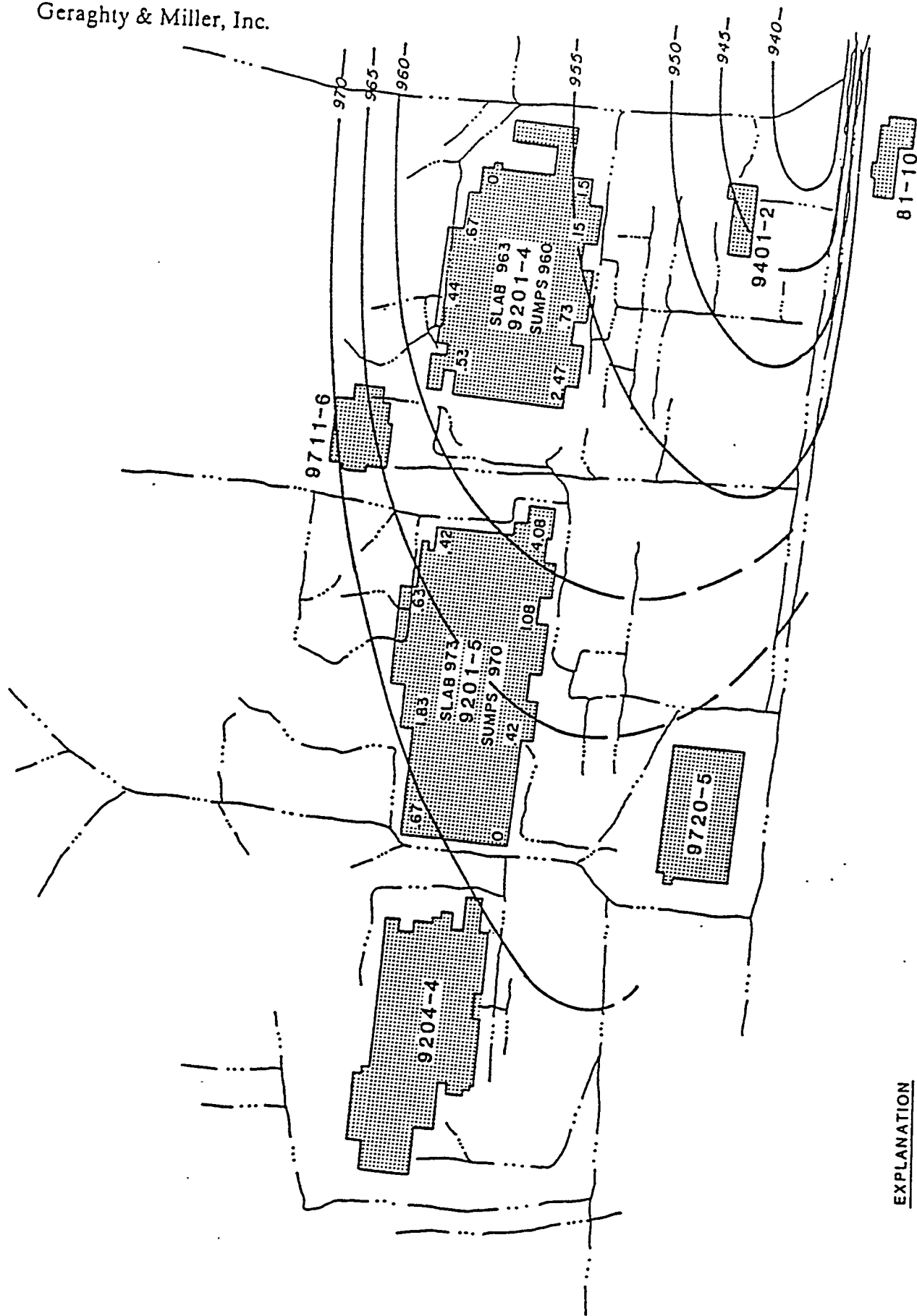


Figure 7. Potentimetric Surface, Unconsolidated Material, and Sump-Discharge at Buildings 9201-4 and 9201-5.

the largest flow measured to date. Energy Systems plans to treat the sump water prior to releasing it to the storm-sewer system.

## 5.0 PROPOSED REMEDIAL ACTIONS

### 5.1 RENOVATION OF STORM DRAINS

Energy Systems is considering a plan to remediate the mercury problem that would involve (1) lining the drains to block infiltration of ground water, (2) removing particulate mercury from sumps and drain traps, and (3) cleaning up mercury within the buildings. Mercury in the soil would be left in place in view of its negligible potential for being transported in ground water.

The presence of the leaking storm-drain system, as previously mentioned, has become a factor in modifying ground-water flow in the unconsolidated material, resulting in a northward shift of the natural, or pre-drain, axis of the flow system, as shown in Figure A-1. Lining of the drains would not prevent movement of ground water along and through the permeable gravel envelopes surrounding the drains. Also, lining the drains, in places where they are below the water table, will cause the water table to rise. As part of this study, an effort has been made to predict the extent to which the water table will rise along various segments of the drains. The assumptions and methods used for estimating were as follows:

1. Elevations of the drain invert at key intervals were taken from the detailed maps of the drain system. These elevations were compared with water-table elevations to

determine an average head difference between the water table and the drain. Water-table elevations from Figures A-1 and A-5 were used because the May 5 measurements were, on average, the highest for the year. In places where the head in the deep aquifer is higher than in the shallow aquifer, as at site 56-1 for example, the higher elevation was used.

2. A hydraulic conductivity of  $4.3 \times 10^{-4}$  cm/sec for the shallow aquifer was used as the average from five slug tests in shallow wells reported by Rothschild (1984).

3. A coefficient of storage of 0.1 was assumed for the water-table aquifer. An equation derived by Stallman (in Ferris, 1962) was used to calculate the volume of drainage from the water table to each segment of drain.

4. It is assumed that the drain pipes were laid in gravel in accordance with American Clay Pipe Institute standards. On that basis, the cross-sectional area of the gravel bed was calculated for pipes of different diameter.

5. Hydraulic conductivity of gravel ranges widely. Gravel beds at Y-12 are reported to be of one-inch, river-run gravel, which would be relatively permeable. In places where the pipe is corroded away, however, it is noted that cementation of the gravel bed has taken place. After 40 years, it would seem that some fine material has washed into the gravel bed and reduced the permeability; a hydraulic conductivity of 0.5 cm/sec is taken as a reasonable value.

6. The gradient in each drain segment is known from the invert elevations, so that a volume of flow through the gravel bed could be calculated for each segment by multiplying the gradient by the hydraulic conductivity and the cross-sectional area of the gravel bed.

Estimates of ground-water flow to the drain pipes and gravel beds are indicated on Figures 8 and 9. The numbers shown at intervals along the drains represent the cumulative seepage in the drain and the carrying capacity of the gravel drain bed from the upgradient direction. It is apparent that in many segments of the drain system ground-water leakage exceeds the capacity of the gravel beds alone. The potential for overloading the gravel-bed capacity apparently increases downgradient in spite of the relatively larger volume of gravel buried with the large-diameter pipes downgradient.

The flow capacities shown on Figures 8 and 9 are best estimates from the data available, but must be viewed with extreme caution. The actual gradient impressed on the gravel bed, for example, will depend on the heads in the shallow aquifer at the point of discharge and upgradient from it. This in turn will be affected by local recharge rates which will depend on such factors as whether the area is paved or open ground. In any event, it seems clear that sealing the drains, in places where they are below the water table, will cause the water table to rise to some extent.

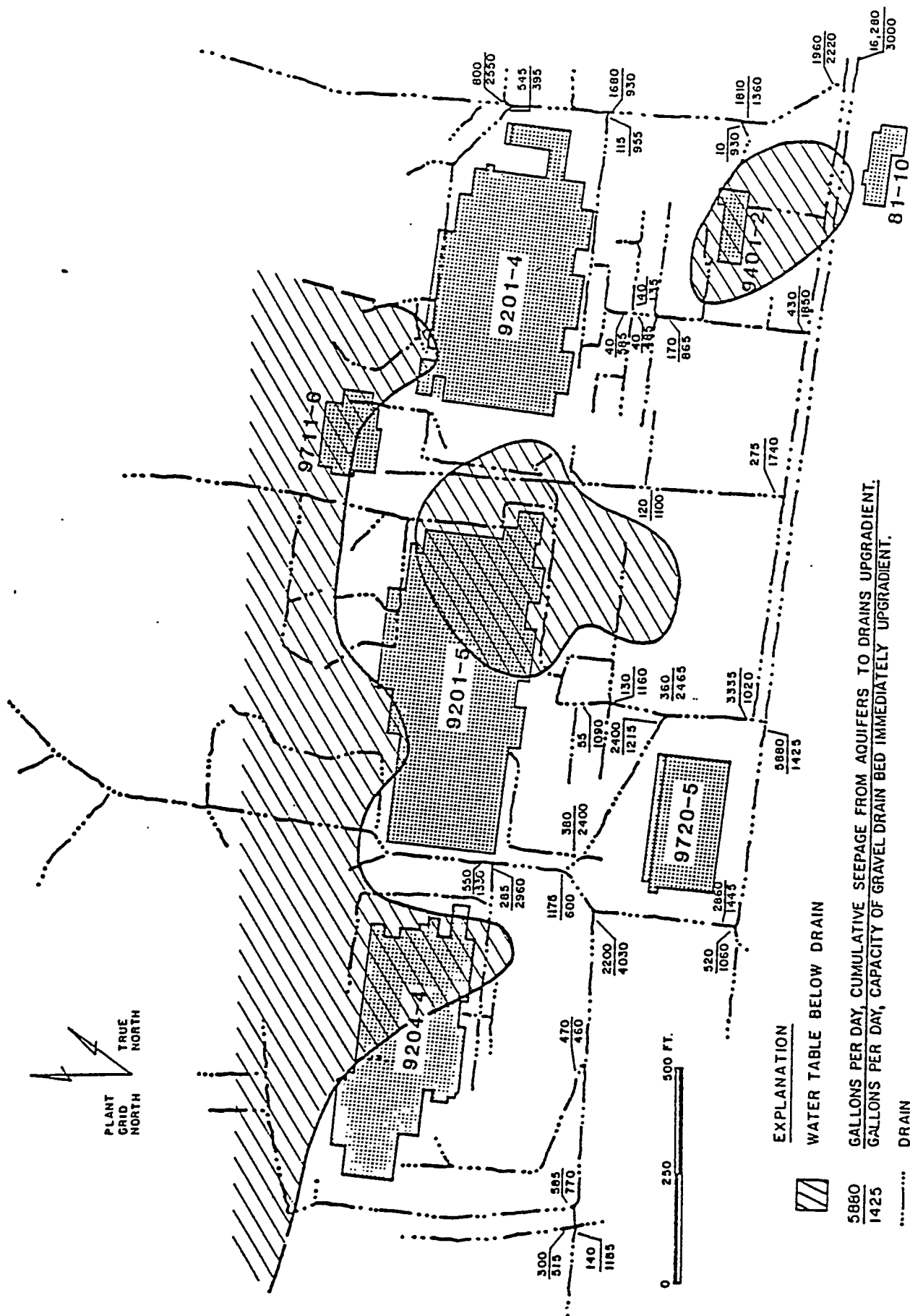
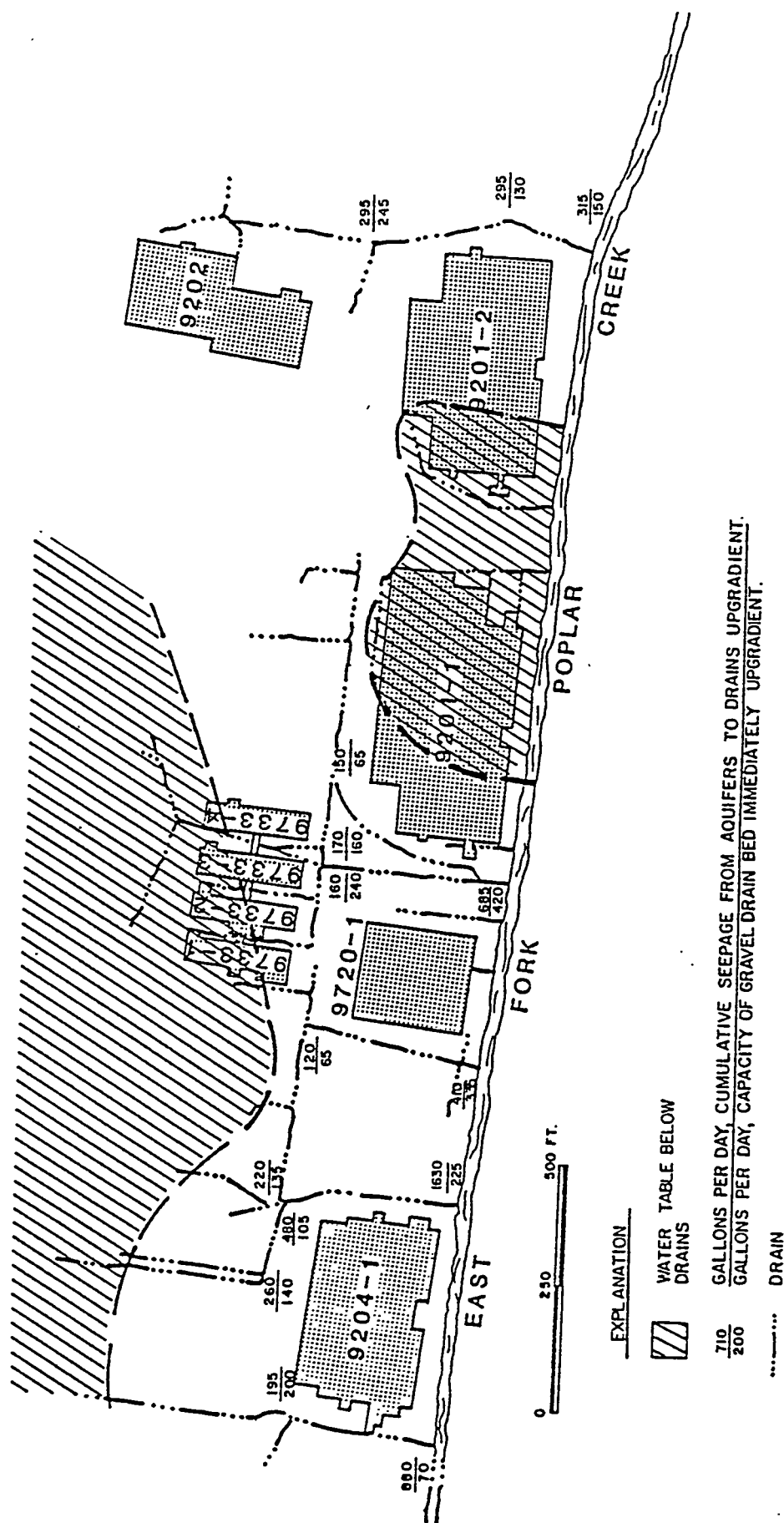


Figure 8. Flow Potential Between Ground Water and Storm Drains, Western Area.



**Figure 9. Flow Potential Between Ground Water and Storm Drains, Eastern Area.**



There is no reliable way to accurately predict the rise of the water table, owing to the various assumptions made in the analysis and the uncertainties regarding water-table elevations and recharge rates at all points in the plant area. As previously mentioned, however (2.4), subdrain systems beneath the buildings should prove adequate to handle any rise in the water table.

## 5.2 INTERCEPTION OF SPRING DISCHARGE

If it is determined that the pipes discharging mercury-contaminated water from Building 9201-2 are indeed tapping the spring previously mentioned (4.4), it might prove less expensive to divert the water before it becomes contaminated rather than to remove the mercury from the water. This could be done by installing and pumping a well close to the spring. The water issuing from the spring conduit would thereby be removed, before it could become contaminated, and discharged to East Fork Poplar Creek. A well could be located southeast of the spring, so that the open-hole section of the well intercepts the stratigraphic section of rock that crops out in the vicinity of the spring. Pumping the well then would lower the head in the aquifer and capture water that otherwise would flow upward into the mercury-contaminated soil.

Results of aquifer tests conducted in the Nolichucky shale indicate that a drawdown of 50 ft could be maintained in a well by pumping 3.75 gpm. Initially, the drawdown will

be greatest along the fractures, but in time, a symmetrical cone of depression will develop.

The cavernous limestone in the vicinity of building 9201-2 will yield considerably more water to a well than the Nolichucky Shale, but its cone of depression will be more extensive radially and not as deep as the cone in the shale. Velocity of flow will be too slow to carry particulate matter when the well has been properly developed.

Dewatering the aquifer beneath Building 9201-2 might induce movement of high-nitrate (low pH) water from the vicinity of the S-3 Ponds. This acid water would not mobilize mercury in the soil because it would be moving through the bedrock aquifer beneath the mercury-contaminated zone. The water would need to be treated for removal of nitrates and other contaminants, however.

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APPENDIX A:  
POTENTIOMETRIC SURFACE MAPS

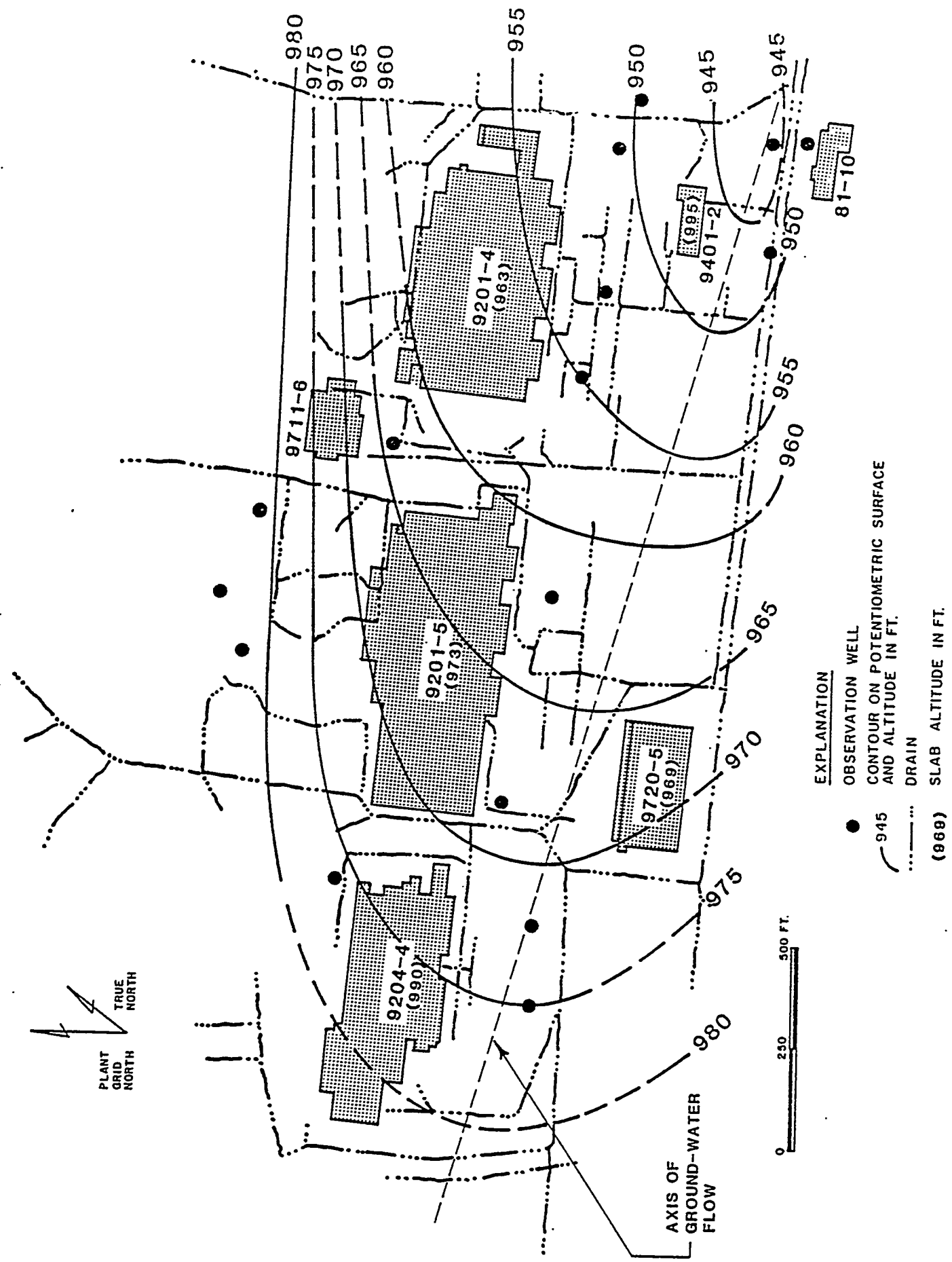


Figure A-1. Potentiometric Surface, Unconsolidated Material, Western Area, May 4, 1984.

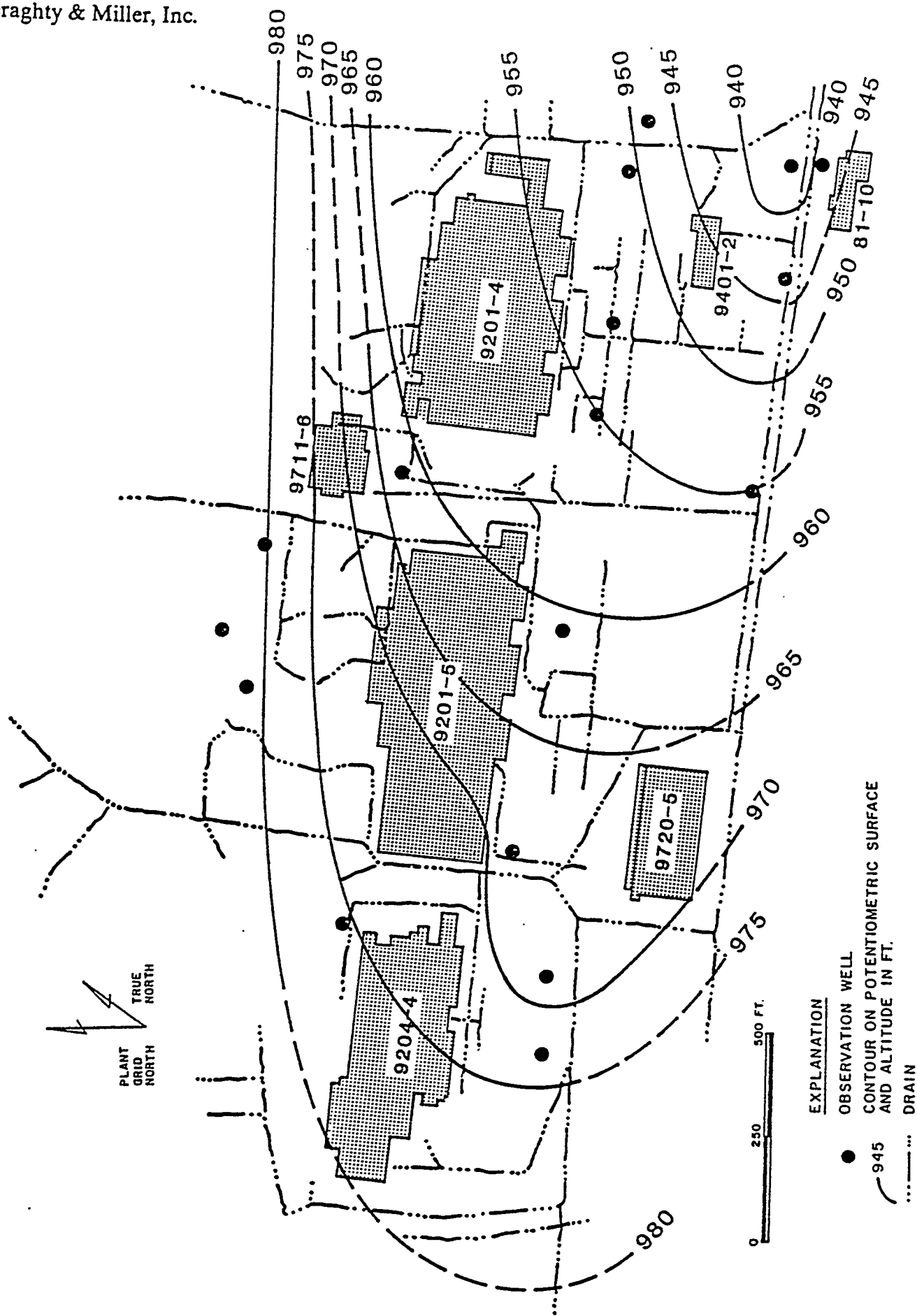


Figure A-2. Potentiometric Surface, Unconsolidated Material, Western Area, September 17, 1984.

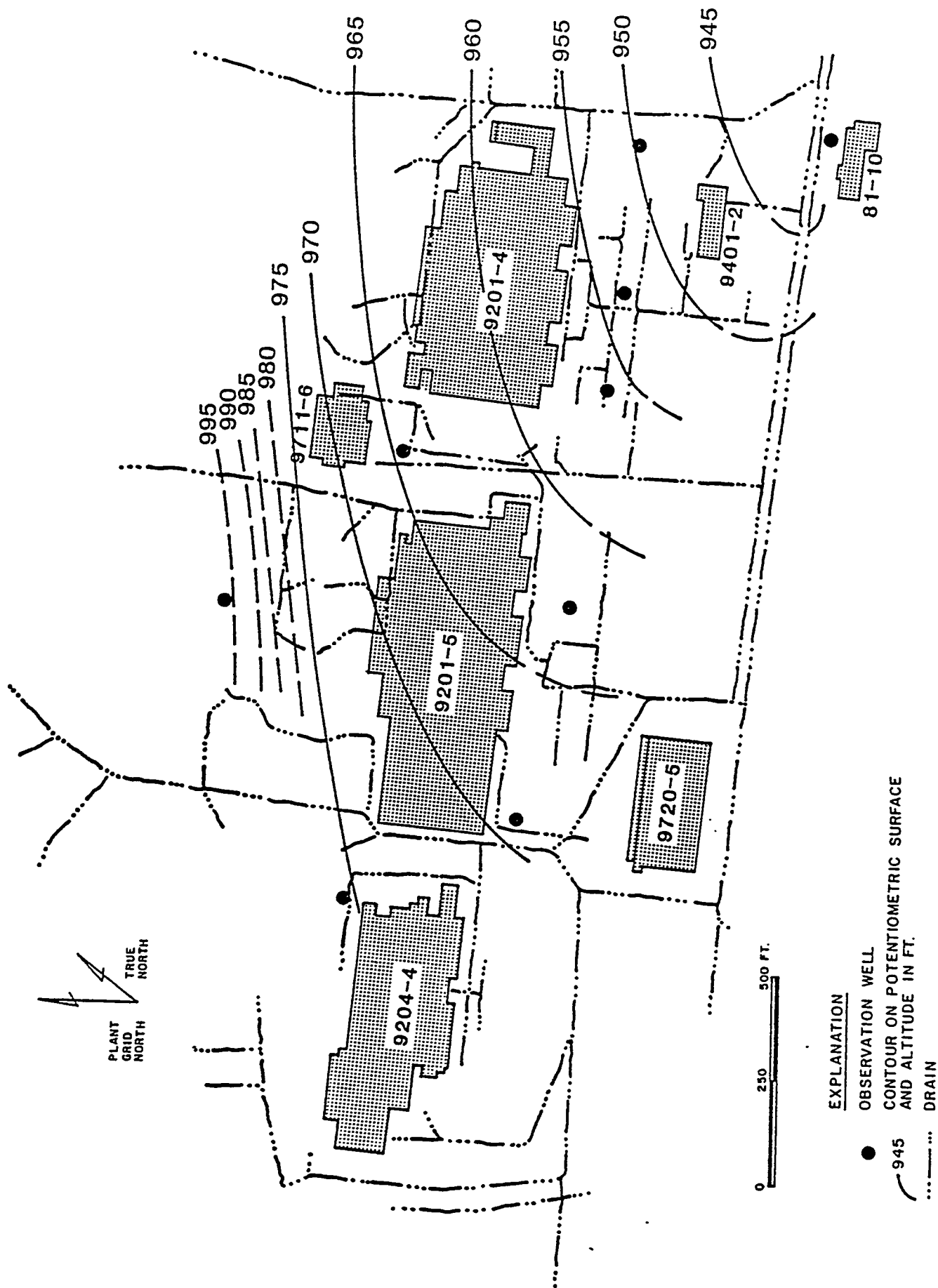
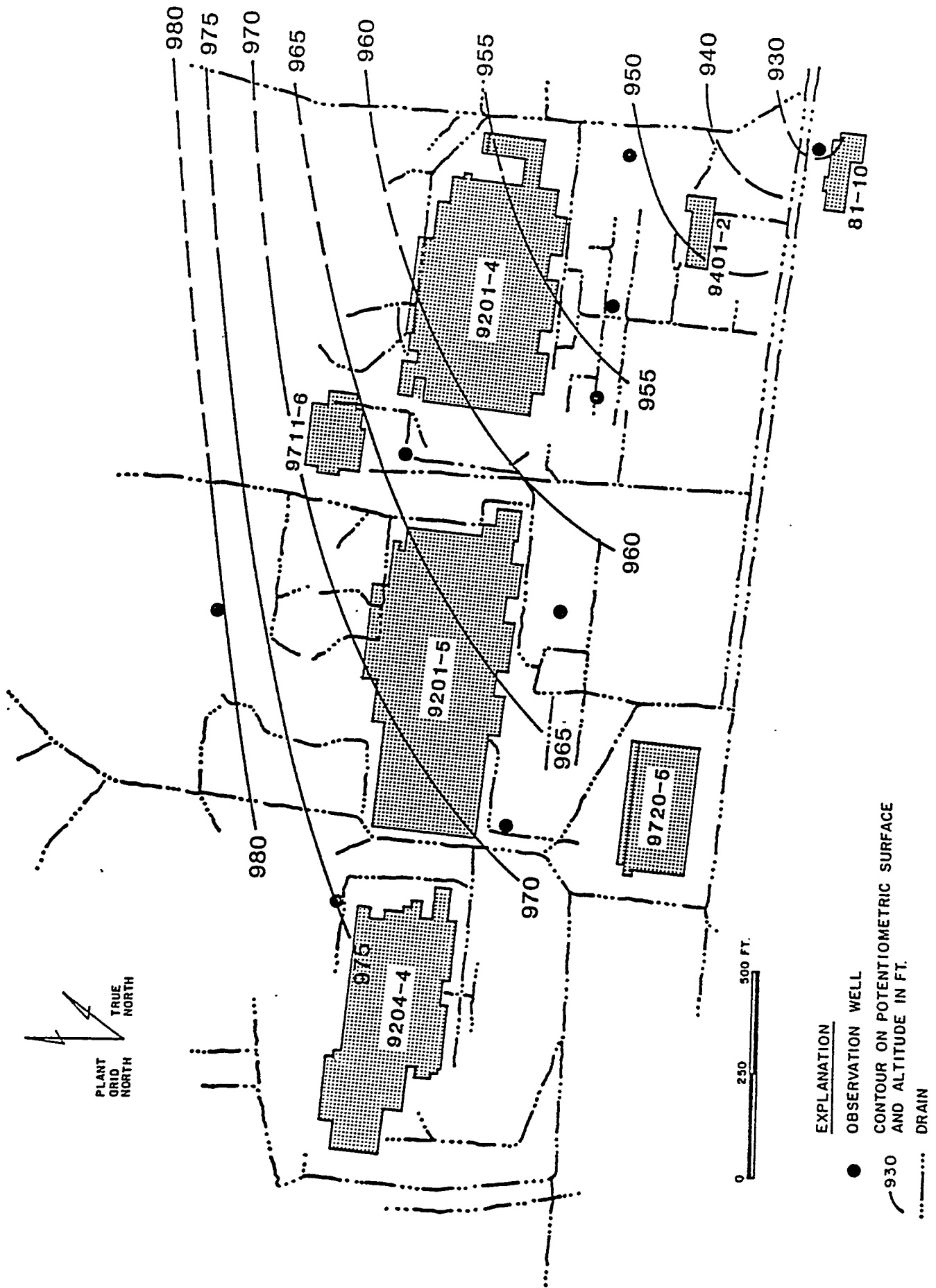
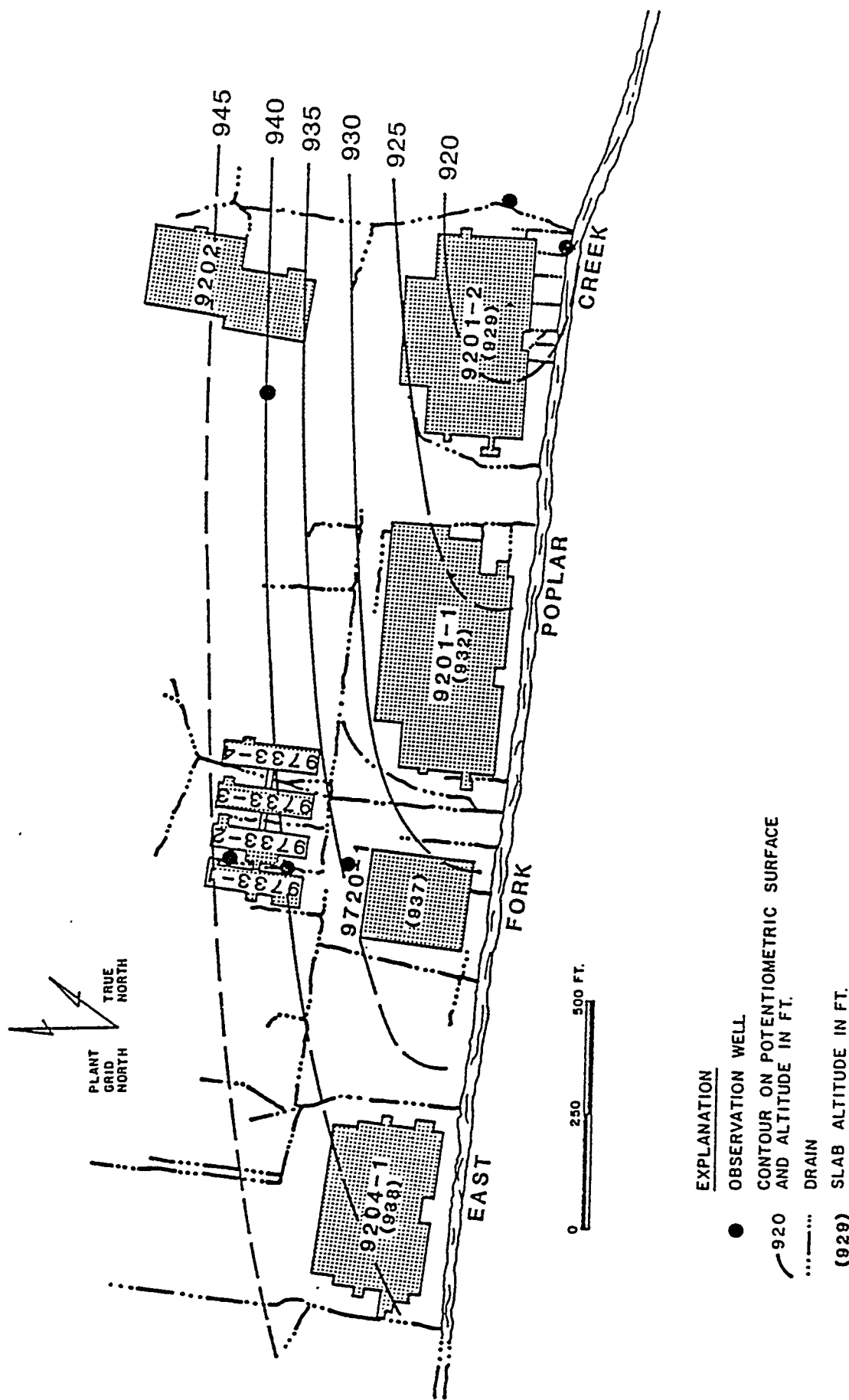


Figure A-3. Potentiometric Surface, Bedrock, Western Area, May 4, 1984.







- EXPLANATION**
- OBSERVATION WELL
  - 920 AND ALTITUDE IN FT.
  - DRAIN
  - (929) SLAB ALTITUDE IN FT.

Figure A-5. Potentiometric Surface, Unconsolidated Material, Eastern Area, May 4, 1984.

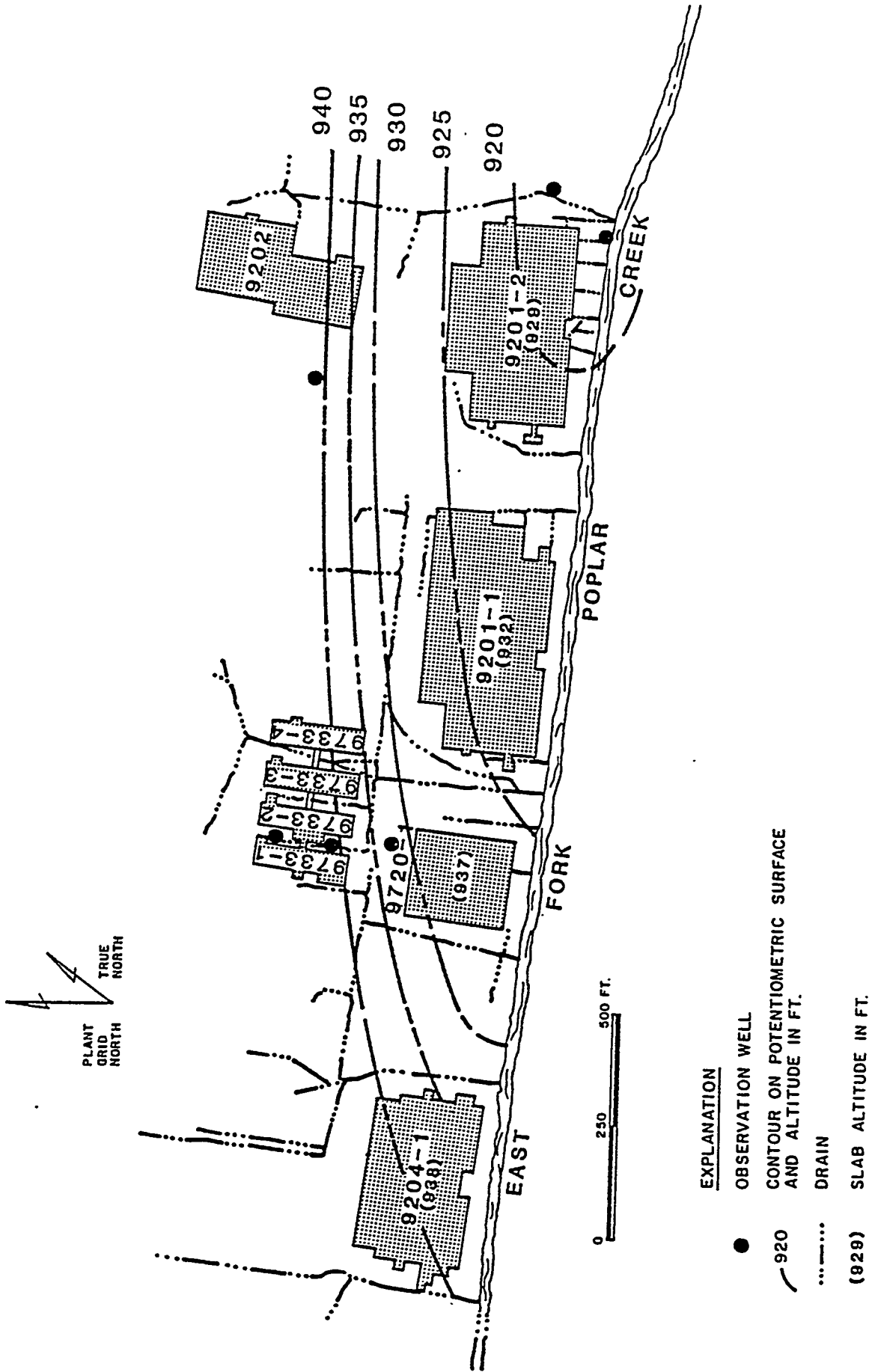


Figure A-6. Potentiometric Surface, Unconsolidated Material, Eastern Area, September 17, 1984.